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ABSTRACT

This document discusses the relation between adolescents' expertise (their informational background, which can be accurate or inaccurate, about a particular task or subject) and their formal operational reasoning, and reports the results of three studies of the effects of children's expertise on reasoning. In Study I, adolescents from a rural river delta area were compared with urban students in an experiential science program on three measures of the ability to control variables involving fishing, bending rods, and a third for which neither group had previous relevant experience. The river delta students performed better on the fishing task than on bending rods, the converse was found for the science students, and the two groups performed equally on the neutral task. In Study II, which involved high school seniors, a relationship was found between the ability to name variables in a particular problem and the ability to control them, and a relationship between field dependency and the ability to name variables. Study III examined the effects of prior expertise (accurate and inaccurate) and experience (increasing expertise) on the reasoning of seventh graders. Experience was found to influence reasoning, but the effects of experience were sometimes blocked by prior inaccurate expertise. These findings are discussed in connection with other relevant variables, e.g., field dependency and the question of whether or not to employ a given strategy (e.g., controlling variables). (BH)

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THEORETICAL AND PRACTICAL SIGNIFICANCE OF FORMAL THOUGHT:
SOME CONSIDERATIONS

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A qualitative change in logical reasoning ability during adolescence has been described by many researchers (e.g., Peel, 1971). Formal thought is a stage of cognitive development which emerges during adolescence according to Piagetian theory. Definition of a psychological construct of formal reasoning is in question. Research on formal reasoning has focused on the presence or absence of schemes or strategies described in Inhelder and Piaget's (1958) monumental work on adolescent reasoning. Previous research (see Levine and Linn, 1977; Neimark, 1975) primarily documents whether or not formal reasoning strategies exist at particular ages or in particular groups.

In this paper I will argue that further understanding of strategy acquisition requires emphasis on when strategies are applied and what factors influence strategy application. Researchers have found that performance across tasks designed to measure formal reasoning is not consistent or widespread (e.g. Lovell, 1961; Martorano, 1977). These results suggest that formal reasoning may not be a valid construct or a universal acquisition. Few studies have focused on multiple measures of the same strategy and most studies have used only problems from physics for measuring formal reasoning. These confounds and omissions in the available research have led investigators to some dubious conclusions. For example, designers of educational programs have implicated formal reasoning in statements about readiness (e.g. ADAPT, 1977). It is not surprising to find that remedial science courses use tests of formal thought as evaluation measures, assuming that these tests measure acquisition of strategies which will be necessary in future technical course work. Group tests of formal reasoning have been developed (e.g. Lawson, 1978) and described as measures of a well established construct. These uses of measures of formal reasoning are premature and perhaps hazardous; they are certainly not justified on the grounds that a well established construct of formal thought exists. No such construct has been

identified and the existence of such a construct, different from standard measures of achievement and general ability is far from certain (e.g., Linn and Pulos, 1979; Linn, 1978a).

Two limitations of the current state of knowledge about a formal thought construct are described above. These are: 1) few studies use multiple measures of the same strategy so reliability of strategy application is not well documented and 2) most studies of formal reasoning use tasks from physics so results are confounded with the problem domain of physics. These two limitations of measurement of formal reasoning are of critical importance in developing a construct with educational implications. In this paper I will discuss current research in light of these limitations and describe some preliminary studies which suggest how these limitations impact on performance on formal reasoning tasks.

Basically, the current work on formal reasoning has neglected factors that differentiate two tasks that measure the same strategy. If we have the traditional measure of controlling variables, Bending Rods, and another measure of controlling variables, say a task about which variables influence how many fish are caught in a pond there are many differences between the tasks. Differences include the content area of the task (bendability of rods or catching fish), the availability of apparatus to provide feedback, and the expectations of the subject concerning how difficult the task is.

In our research we call factors that differentiate tasks requiring the same strategy, context factors. Piaget has called these factors "resistances". Piaget has written a variety of things about context factors or resistances. In one paper (Piaget, 1971) Piaget said that resistances could not be predicted but only interpreted after the fact: "When one encounters them[resistances] one can explain them, but always after the event. It is not possible to have a general theory of these resistances" (1971, p. 11). This seems an

unduly pessimistic view and is somewhat counter to Piaget's notion of "decalage" which refers to the sequence of generalizability of a particular strategy. Decalage in conservation experiments have been verified for mass and weight (e.g. Flavell, 1963). Decalage may describe a sequence of generalization for a strategy but they do not explain the sequence. Sequences based on task demand determined by task analysis have been isolated by neo-Piagetian researchers for formal reasoning strategies (e.g., Scardamalia, 1977, Note 1; Case, 1974) but only a small number of dimensions have been considered in these studies. The variety of factors that influence generalizability of strategy application require a more systematic understanding and, in our view, can be used to predict performance.

Piaget has also discussed context factors or resistances specifically for formal reasoning. In his 1972 paper, he suggests that formal reasoning might be more accurately measured in a person's area of expertise. No data for this view is offered but Piaget appears to be saying that measurement will be more valid or more representative of the formal reasoning construct in the person's area of expertise. As we discuss in this paper, expertise does influence performance but not by increasing validity. Expertise may change the nature of the problem such that formal reasoning strategies are less relevant to problem solution, thereby reducing validity. Certainly measurement of reasoning in an area of expertise is likely to be reliable since knowledge of the area is well established and understanding of the problem may be facilitated by expertise. Thus, performance on one occasion is likely to be consistent with performance on another occasion. Piaget may have been considering reliability rather than validity in his 1972 assertion.

Finally, Piaget (1977) has stressed, in discussing the development of thought that resistances or context factors are an important part of the

equilibration process. He suggests that tasks in new contexts which require strategies that have previously been used in other contexts may disturb the equilibrium for the strategy and lead to a higher level of equilibrium. The task in a new context may illustrate a difficulty in applying the developing strategy and leads to accommodation of the strategy to the new information. This accommodation of the strategy results in a higher level of equilibration for the strategy. Thus context factors are necessary for development of strategies.

Piaget has not neglected the role of context in logical development but he has suggested that the role of context effects is unpredictable. Presumably, Piaget's statements concerning context effects could be unified to suggest that: 1) Each individual's unique experiences with objects and events influences the order of generalization of a strategy. (Note that strategy generalization may be constrained by the acquisition of another strategy as sometimes occurs in vertical decalage but is also influenced by experiences.) 2) Generalization is part of the process of equilibration. 3) As a strategy is generalized the influence of context factors diminishes. 4) Measurement of an individual in his area of expertise will result in measurement of his strategy application performance at the optimum level. 5) Measurement of the strategy in an area of non-expertise will introduce unsystematic performance due to unpredictable context effects. This formulation offers a pessimistic view of the predictability of context effects. Our research suggests that this view is unwarranted. Furthermore, understanding of context effects is critical for developing educational programs.

The educational implications of understanding the role of context effects follows from the Piagetian formulation. If context effects can foster higher levels of equilibration, then study of context effects will

provide guidance for designing programs to maximize the influence of context. In addition, educators are interested in how to design instruction to insure generalization of a particular strategy to an important educational problem. For example, generalization of the controlling variables strategy to selecting the best contraceptive or using the most efficient study habits is an important goal of modern education. Understanding how to design instruction to be relevant to these practical problems will be enhanced by understanding of the role of context effects in reasoning. In order for a formal reasoning construct to have "practical validity" it must be more immediately relevant to naturally occurring problems.

RESEARCH ON CONTEXT EFFECTS

In this section we discuss research on context effects that suggests how systematic understanding of context factors might eventually be achieved. Our work in the Adolescent Reasoning Project, a National Science Foundation funded research project at the University of California at Berkeley is concerned with understanding context effects. In this paper we will focus on one particular context effect and one strategy. The strategy which we are researching is controlling variables. In order to maximize the depth of our research we have chosen to focus on a single strategy and the adolescent age range. Research indicating the limited unity of formal reasoning makes this a sensible decision (e.g., Martorano, 1977). Generalization of our results to other strategies awaits future research. In our research we have emphasized two types of context factors. These are expertise and task demand. In this paper we will confine the discussion to expertise factors. A discussion of some of our work on task demand is found in Linn and Pulos (1979).

Expertise or knowledge relevant to a particular task undoubtedly influences performance, but how? Expertise refers to knowledge about a particular

task or subject and can be accurate or inaccurate. A number of researchers have considered the problem of expertise in performance on learning tasks. The work of Chi (Note 2) is illustrative. Chi has shown that young children and adults perform similarly on tasks of clustered recall and associative memory when their knowledge base for the subject matter area is comparable. She has found that accurate expertise fosters adultlike performance in young children.

Availability of Expertise

At about age 12 or 13, students in the American school system are exposed to opportunities for selectively developing expertise. At this time most schools begin to offer options in the school program, such that students can pursue science or cooking or art with greater concentration than has been available previously in the school system. In addition, as students get older the difference in available information between students is continuously increasing. By the period of adolescence, variety in informational backgrounds become a major source of variance between individuals. Whereas, counting is a fairly universal achievement of 10 year olds, proportional reasoning is far from a universal achievement of 14 year olds and acquisition of information about scientific phenomenon such as, Bending Rods, is not distributed evenly in the population. Interests determine levels of expertise. For example, some students become interested in motocross competition and become very knowledgeable in this area, while others become interested in fishing and become very knowledgeable in that area. In order to fully comprehend reasoning in naturally occurring problems the unevenness in informational background of the subjects needs to be considered.

Let's consider an example of how expertise might influence reasoning conducted by an adolescent. When we present uncontrolled experiments using the

Bending Rods apparatus and ask subjects to criticize them, two predominant forms of response are discriminable. Some subjects when presented with an uncontrolled experiment respond, "That's not a good experiment, you are investigating the material of the rod, but you also changed something else. Its fair only if you change one thing at a time, so that's not a good experiment." Other subjects presented with the same problem respond by saying, "You can't do the experiment that way, thin rods bend more than thick rods. How are you going to find out about the material when thin rods bend more." The first subject solved the problem without considering whether thickness influences the outcome, but instead by applying a strategy. The second subject, rather than applying a strategy, cites a fact as evidence for the viewpoint presented. We find that some subjects employ strategies for solving these sorts of problems, while others rely on expertise. Expertise, while often working in a positive direction, can also work in a negative direction in that subjects who base their reasoning on inaccurate expertise may fail a problem when they believe that a particular variable doesn't make a difference. Such a subject might say, "It's okay to use a thick rod and a thin rod because the thickness of the rod doesn't influence how much the rod bends. You can still find out about the material."

Magnitude of Expertise Effects

Several studies of formal reasoning have used tasks which require different types of expertise in that they are from different content domains. These studies suggest the potential magnitude of expertise effects. These studies demonstrate, as one would expect, that when context effects are increased by selecting tasks from a wider range of contexts, the common variance between tasks decreases. Studies that employ laboratory tasks (e.g., Bending rods, Pendulum) to measure the ability to control variables generally find that tasks

measuring the same strategy correlate about .6 or .7, thus accounting for 40-50% of the common variance between tasks (Case, Note 3; Linn and Pulos, 1979; Bentley, Note 4). For these tasks the reliabilities are normally .8 or above (thus having 64% or more true variance) suggesting that although there is a reasonable amount of common variance, each task also has specific variance not accounted for by a common factor.

When laboratory and non-laboratory tasks are used, the common variance in the tasks decreases. In a study done by Pulos and Linn (1978a) seven tasks from a wide variety of contexts were used. All seven of the tasks measure the ability to control variables. By increasing the diversity of task context only 17% of the variance between all seven tasks was common. The remaining variance was specific to individual tasks. Reliability for these tasks was reasonably high indicating that much specific variance was available and not accounted for by a common factor. In a similar vein, Kuhn and Brannock (1977) used one laboratory and one naturalistic task measuring what they said was the same strategy. (Inspection of their tasks suggests that the strategies required may differ.) The relationship between the two tasks studied by Kuhn and Brannock was not significant, indicating very little overlap.

It should be noted that in the Pulos and Linn study where seven diverse controlling variables tasks were administered, over 95% of a sample of 130 seventh graders controlled variables on at least one of the tasks. Since the tasks were individually each very reliable, but performance across the tasks was not consistent, it appears that some systematic effects are at work. Level of difficulty of the seven tasks in the group as a whole did not vary greatly, but of course, individuals found different tasks easy.

RESEARCH RESULTS

A series of three studies was carried out to investigate the effects of expertise on reasoning in problems requiring the ability to control variables.

Study I

The first study was, in a sense, a pilot study to investigate how naturally occurring expertise effects reasoning. (Results are partially reported in Pulos and Linn, 1978a.) An ecologically valid comparison was possible by selecting two groups of subjects who had differential levels of expertise and developing tasks relevant to their expertise.

Two groups of subjects were selected that differed in their level of expertise. The first group were seventh graders living in a river delta area. This group frequently engaged in fishing. When queried at the beginning of the interview as to whether they went fishing the subjects responded with such comments as, "Well, I couldn't go last weekend but I'm going next weekend" or "I've got to fix my reel before I go this weekend." The second group of seventh grade subjects lived in an urban area where fishing was an infrequent activity. All of these subjects indicated that they had been fishing once or twice. None of them were frequent fisherpeople. These urban subjects however were participating in an experimental science program and spent several hours a week doing things like investigating the variables that influence how fast an object descends an inclined plane or examining the trajectory of a catapult. The river delta students were engaged in a traditional book oriented science program. Thus, these two groups differed in their expertise in fishing and experimental science.

An evaluation instrument was developed to assess the role of expertise. Two parallel measures of ability to control variables were designed. One involved variables having to do with how to catch the most fish at a pond (shown in Figure 1). The other involved variables having to do with Bending Rods as described by Inhelder and Piaget (1958). A third task was devised employing totally artificial content, but otherwise parallel to the other two tasks. These three tasks were administered to the river delta students and the experiential science students. As shown in Table 1, the results were in the expected direction. River delta subjects performed better on fishing than on bending rods while experiential science students performed better on bending rods than on fishing. Fortunately, since the two groups were not selected to be comparable, performance on the neutral task was virtually identical in the two groups.

 Figure 1 and Table 1 about here

Of course, the evaluation instruments used in this study did not require expertise. Subjects could have solved the problems presented without any knowledge of fishing or of experiential science. Yet, as shown, expertise influenced ability to actually solve the problems, and indeed subjects who had expertise in a given area performed better than those who did not.

The results of this study give us a general indication that expertise might influence logical reasoning but they don't really answer the question of how that influence takes place. A second study was conducted to investigate this finding in greater detail.

Study II

A clue from our first study led to the design of the second study. We noted that subjects in the first study were more likely to name the variables that they thought might influence the outcome of the experiment spontaneously if they had expertise in that area. In the second study we investigated whether ability to name the variables in a particular problem increased the likelihood of those variables being controlled. In order to get a clear test of this hypothesis, it was desirable to select subjects who could apply the strategy for controlling variables in most situations. Thus, a sample was selected where very little variance for strategy availability would exist. A group of sixty high school seniors in an upper middle class community were studied. These students were able to control variables on a large proportion of the tasks that were presented to them.

To test the hypothesis that ability to name variables would be a predictor of the likelihood of variables being controlled, a version of the springs task (Described in Linn and Rice, 1979) was designed. In this task, which is designed to be parallel to bending rods, subjects can hang weights from eight springs suspended from a stand. The springs differ in length, material of wire, thickness of wire, and crosssectional diameter. The interview involved first asking students to name the variables that they thought might influence how much the springs expanded and then asking them to perform three controlled experiments to investigate different variables in the springs apparatus.

We found that, as anticipated, naming a variable did increase the likelihood that it would be controlled. The results for the length variable are shown in Table 2. As can be seen, subjects who controlled the length variable in the three experiments that they conducted were more likely to

have named that variable when asked what variables influence the outcome of the experiment than subjects who didn't control the variable. The weight variable was named by virtually all the subjects and controlled by nearly all of them. The other three variables, fatness of the spring, thickness of the wire and the material of the spring, behaved similarly to length.

Table 2 about here

The interpretation of these results is aided by information on other characteristics of the subjects. In this study we measured the field dependency of the subjects. Field dependency was measured by the embedded figures test and the portable rod and frame test. A field dependency score was achieved by summing standard scores on these two instruments. We found that the field dependency measure was a good predictor of naming variables in the springs task. About half the variance in naming variables was accounted for by field dependency. Subjects who are field independent are more likely to name variables and therefore more likely to control them on the springs task. Thus, it appears that subjects who can overcome an embedding context and keep the essential features of the task in mind perform better. This gives some indication as to how the ability to name variables might influence performance on controlling variables. However, field dependency accounts for only about half of the variance in naming variables, other characteristics of naming variables require exploration.

Study III

In order to further clarify the role of expertise in logical reasoning, a third study was carried out where expertise was manipulated experimentally.

The procedure was to provide directed experience or practice in experimenting with a particular task. This minor intervention is not equivalent to most forms of training, but provided a slight increase in expertise such as might be likely to occur in a natural setting.

The task used for this study was the pendulum. A particularly clever apparatus devised by Read Tuddenham (1970) was employed to eliminate many of the procedural problems that have been discussed by other researchers (Linn, 1977; Pulos and Linn, 1978b; Kerst and Youniss, 1977). Subjects in this study were seventh graders in a middle class environment.

In this study, the Pendulum was administered under three different sets of conditions. The first condition parallels the Piagetian procedure for administering Pendulum. First, subjects were given an opportunity to explore the Pendulum. This particular Pendulum has three variables: The length of the arm, the size of the weight, and the height of the release point. Following exploration subjects were asked to indicate the role of each of the three variables in the frequency with which the pendulum arm passed the midpoint of the pendulum. Subjects received one point if they correctly explained the role of a variable and zero points otherwise. As can be seen in Table 3, most subjects were able to successfully explain the role of one variable and many were able to explain the role of two or three. Rather than using information from the experiments they conducted to explain the effect of each variable, many of these subjects based their explanations on inaccurate expertise. That is, subjects had knowledge concerning how each of the factors would be likely to influence the frequency of the pendulum and used this knowledge rather than the results of the experiment to explain the behavior of the pendulum. As might be anticipated, many subjects indicated that they thought all three of the variables in the pendulum

influence the frequency of the pendulum passing the midpoint. This expectation is consistent with many other physical experiments where variables such as height of release point and weight do influence the outcome. Rather than using their experimental results, then, these subjects used inaccurate expertise to explain the behavior of the pendulum in the first condition.

 Table 3 about here

In order to modify this inaccurate expertise a short training procedure was conducted. The second condition of the study was the training. This training consisted of simply asking subjects to conduct controlled experiments for each of the three variables in the pendulum task. Thus, subjects were asked, "Please do an experiment to show that the weight on the end of the bob influences the frequency of the pendulum." What we found in the second condition, as shown in Table 3, is that significantly more subjects could conduct controlled experiments than had been successful in the first condition. Most of the subjects conducted controlled experiments for two of the variables and many conducted controlled experiments for three of the variables. Thus, these subjects were able to conduct controlled experiments when asked to find out the role of the variables, but they didn't see that as the appropriate procedure for proceeding under the Piagetian administration of the task. A number of possible explanations for this behavior come to mind. It might be that subjects do not have the ability to plan and organize their experiments such that they can gain the information that they need from this experience. Another explanation might be that subjects do not think it's necessary to conduct experiments because they are confident of their inaccurate expertise.

A third condition was then administered. In the third condition, subjects were asked to do the pendulum task again following the Piagetian format. That is, explore and then describe the effects of each of the variables. Surprisingly, some subjects who had conducted controlled experiments which demonstrated that the frequency of the pendulum was not influenced by the weight of the bob, still, during condition three, indicated that actually the weight of the bob did influence the outcome. This information is compelling evidence for the fact that inaccurate expertise is an important variable in performance on the pendulum task. The results also show that many subjects did change from inaccurate to accurate expertise for the pendulum variables and performed better than they did on the initial administration of the task. Naturally, as anticipated, subjects who performed controlled experiments during condition two were more likely to perform successfully on condition three. An outcome of this study is that the training in condition two is not sufficient to overcome inaccurate expertise in all subjects, although it was effective for some.

The results of the study of the pendulum suggest how context effects might influence performance. Direct teaching was not done in this study, yet directed experience with the apparatus led subjects to improve their ability to perform on the pendulum task. The directed experience presented in this task is rather parallel to the context effect that Piaget has described as fostering strategy development. For many subjects, simply the direction to conduct a controlled experiment led to the accommodation of new information about the pendulum and thus superior performance on the Piagetian based version of the task.

CONCLUSIONS

Formal Reasoning

Study III does raise the issue, of what formal operations really is. The evidence in this study suggests that ability to apply the strategy or the second condition of the pendulum task is considerably easier than ability to explain the results of the application of the strategy, the first and third conditions. It appears that there is a step missing in the conceptualization of formal reasoning, in that subjects who are able to control variables may not see controlling variables as an appropriate procedure for solving the individual task or may not use the information from the results of their experiments. Presumably the factor that moderates their decision to employ the controlling variables strategy or to omit that strategy is the expertise that they have concerning the variables in the situation. Thus, subjects who have inaccurate expertise that the weight of the bob on the pendulum influences the period of the pendulum seem uninterested in conducting experiments to verify this information and thus do not successfully solve the pendulum task. The question is whether realizing the need to use the controlling variables strategy is the real characteristic of formal thought or whether simply being able to employ the strategy is the basic premise.

It would seem that some of the discrepancies in performance on tasks that are thought to measure formal reasoning might have to do with this issue. Clearly, the decision about whether or not to use the controlling variables strategy is a more complex one than simply applying the strategy when told to use it. If formal thought is defined as a process which maximizes the outcome of information about the situation then it would include not only applying a controlling variables strategy but making

efficient decisions about when to use the strategy and when not to use the strategy.

This is a complex process. It seems clear that efficient adult reasoning of the most sophisticated type would include not only application of the controlling variables strategy but intelligent choices concerning when to use a strategy and when not to use a strategy. For example, parents frequently when confronted with a child that appears to have an allergy, say, "Oh, he seems to have an allergy, I bet he's allergic to milk" and eliminate milk from the child's diet, along with perhaps other foods like green beans and carrots. A few weeks later the parents might say, "Look the allergy has gone away, it must have been the milk." They might well be right even though they did not control for the effect of green beans and carrots in their investigation. Thus, employment of the controlling variables strategy was not really necessary for these parents in this situation and in fact the procedure that they used was more efficient than a true elimination diet which might have caused them a great deal of unnecessary upset in the household. Clearly an important aspect of efficient problem solving ability is knowing when to use the controlling variables strategy and when the strategy is not necessary. This particular goal would certainly be an important aspect of any educational program designed to foster problem solving skill and logical reasoning ability.

Part of logical reasoning in problem solving concerns using strategies efficiently. Experts clearly decide when to use a logical strategy and when to make an educated guess. An interesting example comes from a study by Pitt (Note 5). She asked adolescents and chemists to determine what subset of 4 substances was present in an unknown. Chemists, significantly more than adolescents made what I call "educated guesses" about the

composition of the unknown and invariably failed the task. Pitt called this behavior "impulsive". This behavior, however, would have been efficient in many cases and evidently was inefficient in this case because the chemists used inaccurate expertise to solve the problem. The important outcome in this investigation is the clear evidence for educated guessing in chemists or "experts" that was not found in adolescents.

Role of Expertise

How do these results suggest that expertise influences performance on controlling variables tasks? If subjects have no expertise at all in a particular area they'll have difficulty figuring out what the variables are that influenced the outcome. Under these circumstances it will also be difficult to set up a controlled experiment. On the other hand, subjects who have perfect expertise in a given subject matter area will not on their own be interested in conducting controlled experiments because they already know the outcome of the experiment that they are likely to conduct. Clearly, experimentation is most likely to take place when subjects have some expertise and know what they need to find out. This situation is illustrated in the diagram in Figure 2. We need more detailed information concerning the role of expertise in problem solving. As we saw in Study III directed experience does add information but is not sufficient to train all the subjects to change inaccurate expertise. As we saw in Study II, knowledge of the variables is an influence on performance but isn't a perfect predictor of performance. As we have also seen in these studies, certain personality and style factors such as field dependency and fluid ability appear to influence availability of knowledge in a given problem situation. All of these factors deserve scrutiny and are likely to eventually lead us to a better understanding of problem solving and give guidance concerning how educational programs can foster this ability.

Figure 2 about here

Piaget's 1972 revision of his views on formal reasoning included the idea that formal thought might be measured more reliably in a person's area of expertise. This is an interesting speculation relevant to the results of Study III. In naturally occurring problems it's likely that experts rarely use the controlling variables strategy because they already know the outcome of the experiment. In one's area of expertise the crucial ability is to decide when to do an experiment and when the information is already available. When experts are told that they must conduct an experiment, three factors are likely to influence performance: 1) experts will know the variables that influence the outcome, or be good at naming variables as shown in Experiment II. 2) Experts will know which variables do not influence the outcome and may not control those variables because they know that the outcome will not change. Thus experts may apply the controlling variables strategy but omit variables that novices would control. 3) Even in their area of expertise, experts may have inaccurate expertise and may fail to control an operative variable because they believe it is not important. For example, until the recent work in New Guinea biochemists did not believe the incubation period for viruses was very long and thus failed to implicate viruses in diseases which occurred long after initial exposure. Similarly astronomers often reach impasses because of divergent views on the existence of unidentified flying objects. These factors modify Piaget's original formulation of the role of expertise and suggest that his 1972 speculation requires elaboration.

Relationship of Controlling Variables to General Ability

As indicated in the introduction to this paper, the relationship between formal thought and general ability has not been sufficiently researched. Two studies suggest that the variance in formal reasoning tasks is accounted for by measures of field dependency, fluid and crystallized ability (Cloutier and Goldsmith, 1976; Linn, 1978b; Linn and Pulos, 1979). The research reported in this paper suggests that expertise or knowledge factors are important contributors to performance on formal reasoning tasks. Presumably the measures of expertise described in this paper would be related to measures of crystallized ability. Thus, formal reasoning tasks do not appear to have unique variance not found in other standard tasks.

Then, why study formal reasoning? Two reasons are compelling. First, formal reasoning problems have practical validity: they are important for solving naturally occurring problems such as selecting the most effective contraceptive. Second, the processes of problem solving, in formal reasoning problems are important because they suggest how educational programs could be modified to more efficiently increase problem solving skill.

No evidence has arisen, however, to suggest that general measures of formal reasoning are superior to measures of achievement or general ability in predicting success in college courses. The use of information about formal reasoning abilities has more precise practical implications than general prediction of performance in complex situations. Further investigation involving precise relationships between performance on one formal reasoning task and another or between performance on formal reasoning tasks and expertise will be useful.

Role of Expertise in Development

Piaget has indicated that context effects have a role in the equilibration

process. However, he sees the role of context as gradually diminishing to the point where, when a strategy is fully developed, the context in which the strategy is applied is no longer an influence on performance. The research reported in this paper suggests a more deliberate and focused role for context effects than described by Piaget. In addition, the current research suggests that context influences may indeed continue throughout the life span rather than diminishing when a strategy is fully developed.

How might we conceptualize the relationship between expertise and strategy development? One possibility is to perceive of this process as a dialectic one. Another possibility is to consider the influence of context from a sort of Kuhnian (1962) perspective.

From the dialectic standpoint we would see a contradiction between observations or knowledge about an event and predictions for an event based on a strategy. In this conceptualization, a contradiction between expertise and the outcome from an available strategy would drive the organism to a synthesis of the two. In the area of controlling variables, the controlling variables strategy might be applied only in situations where all the variables were named. Then expertise might contradict this situation by suggesting the importance of unnamed variables. Ultimately a synthesis which includes a mechanism for seeking and adding unnamed variables might develop. Polarity could again result because, for example, the controlling variables strategy was not effective for designing sequential experiments. Thus, the possibility exists that a dialectical process may be involved in the development of reasoning. Piaget acknowledges a dialectic process in his definition of accommodation and assimilation but suggests that this force diminishes as the individual achieves formal reasoning. It should be noted that the dialectic conceptualization assumes that individuals will continue to

develop to higher levels of sophistication, an assumption open to question and requiring further research. Also, logical independence for expertise and strategies is assumed but some would argue that expertise is logically required for defining a strategy.

An alternative conceptualization of the role of expertise in logical reasoning comes from the Kuhnian (1962) perspective. It could be that expertise is the factor which causes the individual to give up a strategy and form a new and more powerful one. The Kuhnian perspective suggests that context effects incrementally build up until eventually they force a revolution in a strategy that is being used. This viewpoint is consistent with a lot of observations of how logical reasoning is conducted in young children and adolescents and deserves further scrutiny by researchers.

Both of these conceptualizations place a stronger role on expertise than has been the case in the Piagetian formulation. The dialectic approach allows for the possibility of continuous development of strategies throughout the life span, thus, opening up the possibility for a fifth stage of logical reasoning, as suggested by Reigel (1973). Reigel suggested that this stage would be the dialectic stage. The Kuhnian perspective emphasizes the stability of strategy development, relative to context effects, but also describes a definite role for context effects and a process for strategy development. The role of expertise deserves serious study as a factor in development.

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Table 1

Percent of Successful Junior High School Students
(Seventh Graders) on Tasks with Familiar and Unfamiliar Variables

	River Delta Residents N = 40	Experiential Science Students N = 60
Bending Rods	Unfamiliar Variables 20%	Familiar Variables 45%
Fishing	Familiar Variables 50%	Unfamiliar Variables 30%
Neutral Task	30%	27%

Table 2

Relationship between Naming and Controlling
the LENGTH Variable on the Springs Task.

Subjects = 60 High School Seniors

	Number of experiments for which LENGTH was controlled	
	0 - 2	3
LENGTH <u>not</u> named by subject	26.6% (N = 16)	25% (N = 15)
LENGTH named by subject	10% (N = 6)	38.3% (N = 23)

$$\chi^2 = 7.6 \quad p < .05$$

$$\text{Kendall's Tau} = .34 \quad p < .005$$

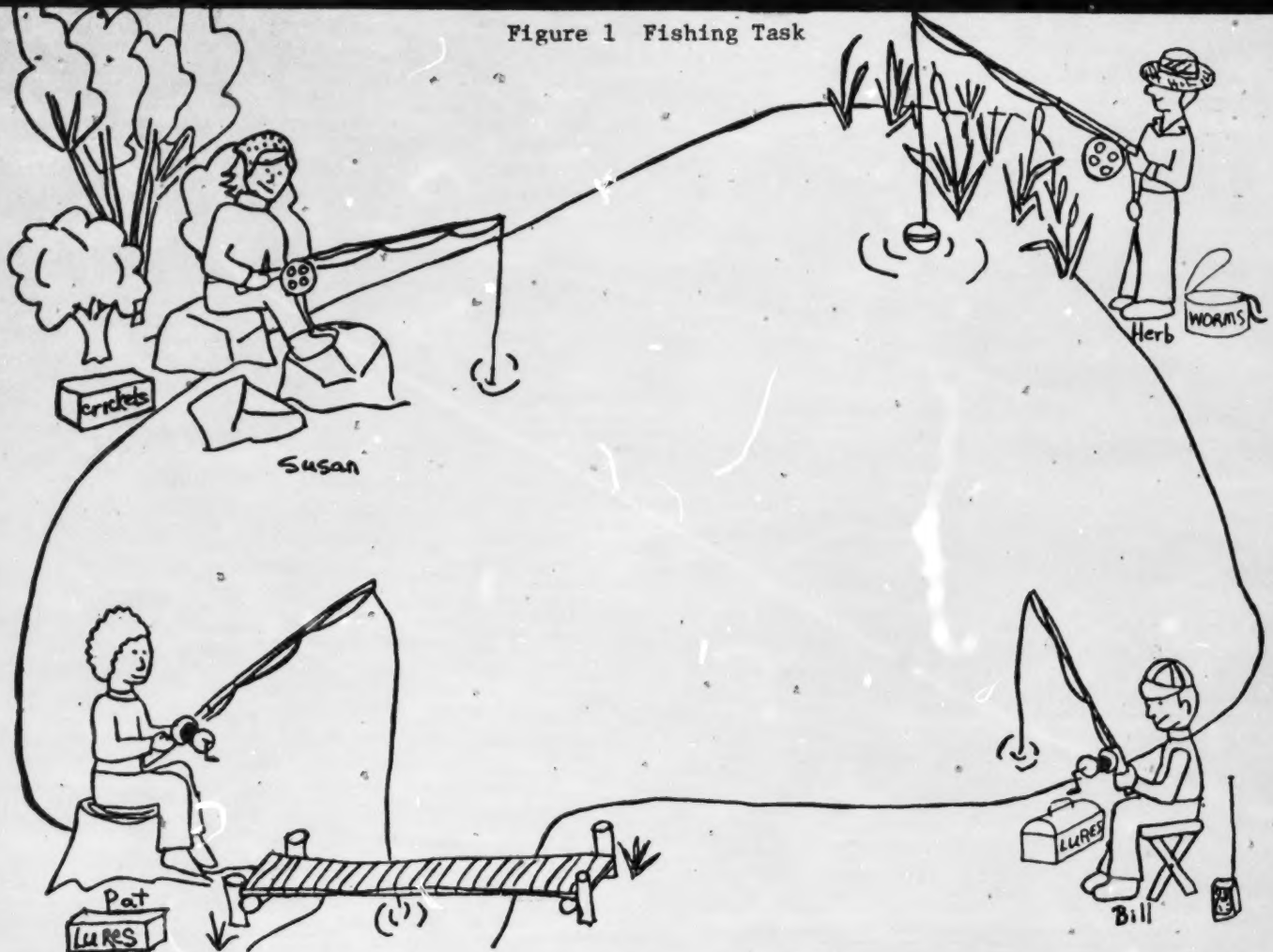
Table 3

PENDULUM: CONTROLLING VARIABLES OR
REASONING ABOUT RESULTS*

	Spontaneously Reason About Results	Perform Controlled Experiments	Reason About Results After Doing Experiments
Mean Score (possible of 3)	1.75	2.37	2.03
	(each score significantly different from each other score)		
Correlation With Spontaneous Controlled Exp.		.18	.44 .24

*Linn, M.C., Science Education, 1977, 6, 357-369.

Figure 1 Fishing Task



(Show picture and variables card.) Every weekend Herb, Susan, Bill and Pat go fishing at the same pond. In this pond the only things which make a difference in the number of fish caught are the kind of bait, the bobber, the kind of reel, whether or not the radio is playing, and the location of the fisherperson.

5. Suppose you could tell each person where to fish and what kind of bait, bobber, and reel to use. What would you tell them to do to find out if the kind of bait made a difference in how many fish were caught? (Use record sheet.)

Recording Sheet: Fishing

Person: Herb (H) Bill (B) Susan (S) Pat (P)

Bait: Worms _____ Lures _____ Crickets _____

Place: Trees _____ Bridge _____ Weeds _____ Plain _____

Bobber: Uses Bobber _____ No Bobber _____

Reels: Reel A _____ Reel B _____

Radio: Uses Radio _____ No Radio 32

Figure 2

RELATIONSHIP BETWEEN STRATEGY EMPLOYMENT AND EXPERTISE

